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Cooper

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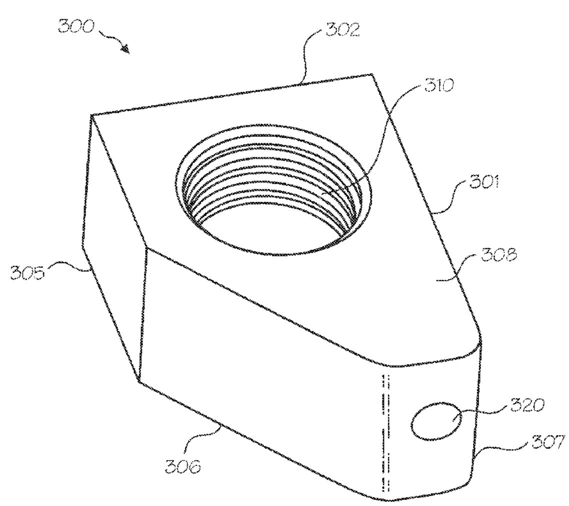
(57) **ABSTRACT**

The present invention includes a molten metal pump and associated components that enable gas to be released into a stream of molten metal. The gas may be released into the molten metal stream (preferably into the bottom of the stream) flowing through a passage. Such a stream may be within the pump discharge and/or within a metal-transfer conduit extending from the pump discharge. The gas is released by using a gas-transfer foot that is positioned next to and is preferably attachable to the pump base or to the metal-transfer conduit. Preferably, the conduit (and/or discharge) in which the gas is released comprises two sections: a first section having a first cross-sectional area and a second section downstream of the first section and having a second cross-sectional area, wherein the second cross sectional area is larger than the first cross-sectional area. Preferably, the gas is released into or near the second section so that the gas is released into an area of relatively lower pressure.

14 Claims, 22 Drawing Sheets



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continuation of application No. 11/413,982, filed on Apr. 28, 2006, now abandoned, which is a continuation of application No. 12/120,190, filed on May 13, 2008, now Pat. No. 8,178,037, which is a continuation of application No. 10/773,101, filed on Feb. 4, 2004, now abandoned, which is a continuation of application No. 10/619,405, filed on Jul. 14, 2003, now Pat. No. 7,507,367, which is a continuation of application No. 10/620,318, filed on Jul. 14, 2003, now Pat. No. 7,731,891.

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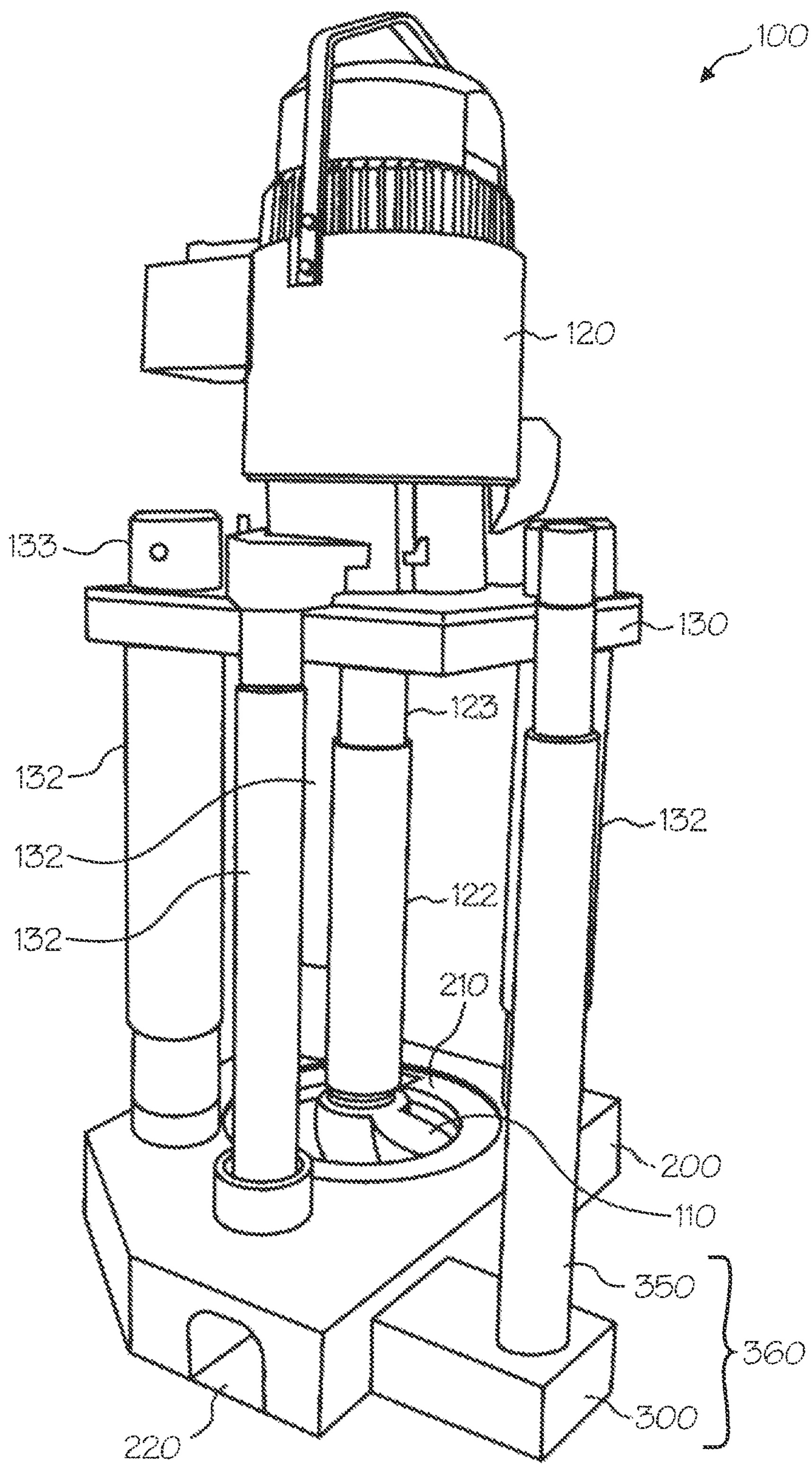
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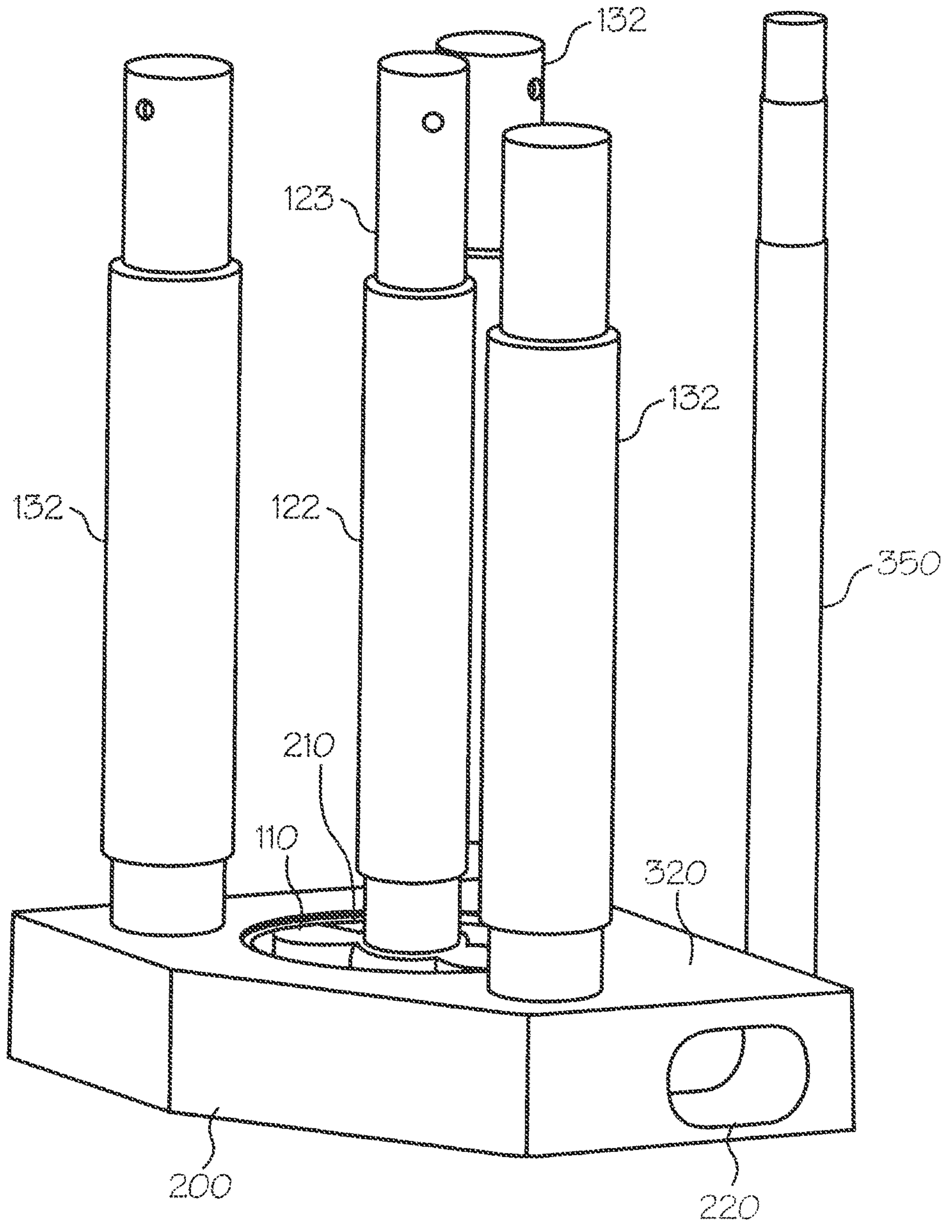
Fig. 1A



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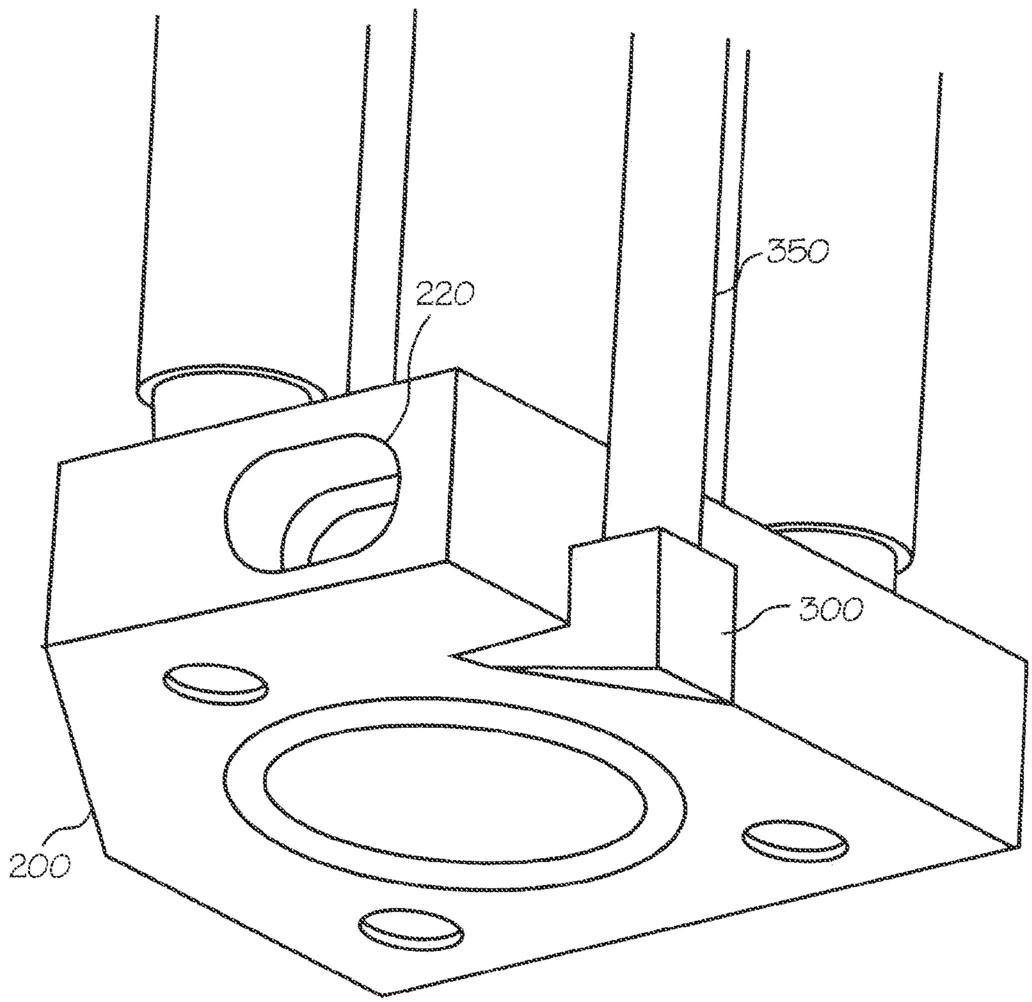

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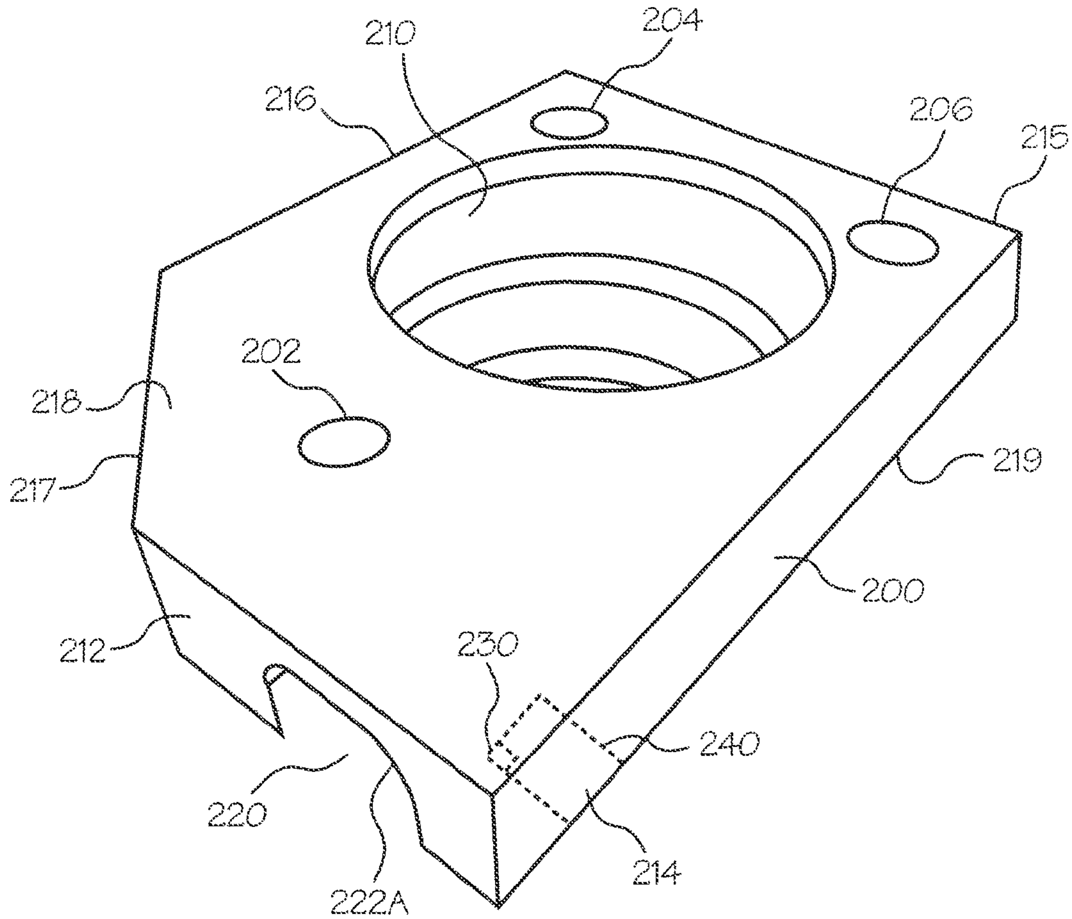

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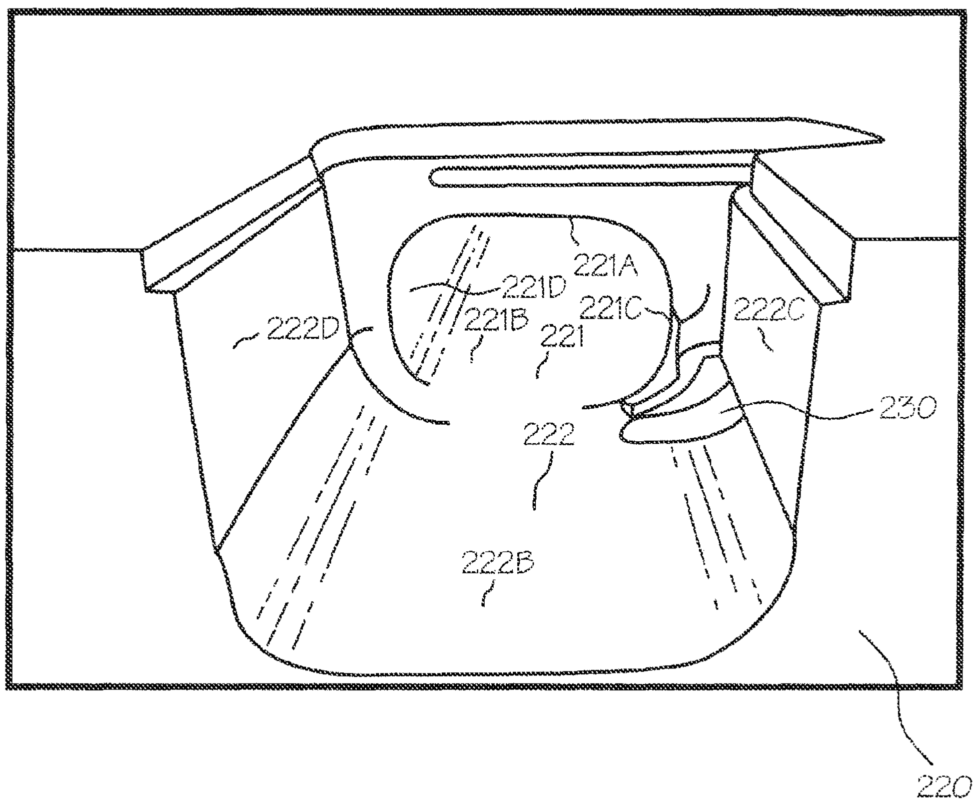

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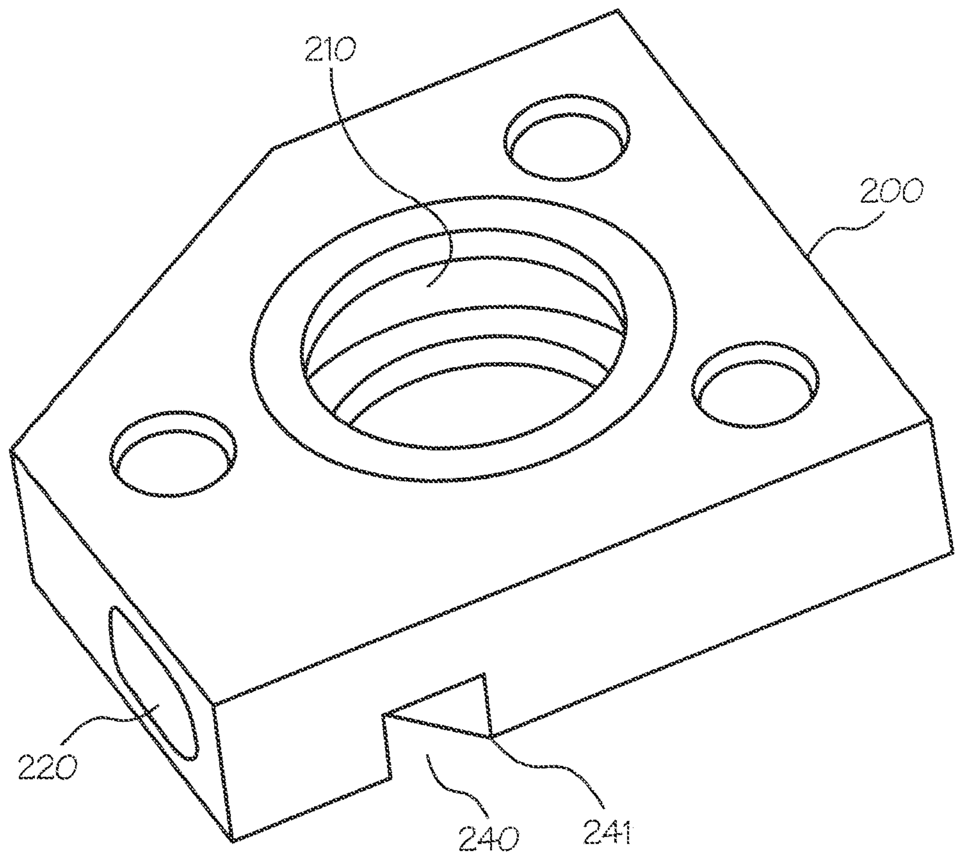

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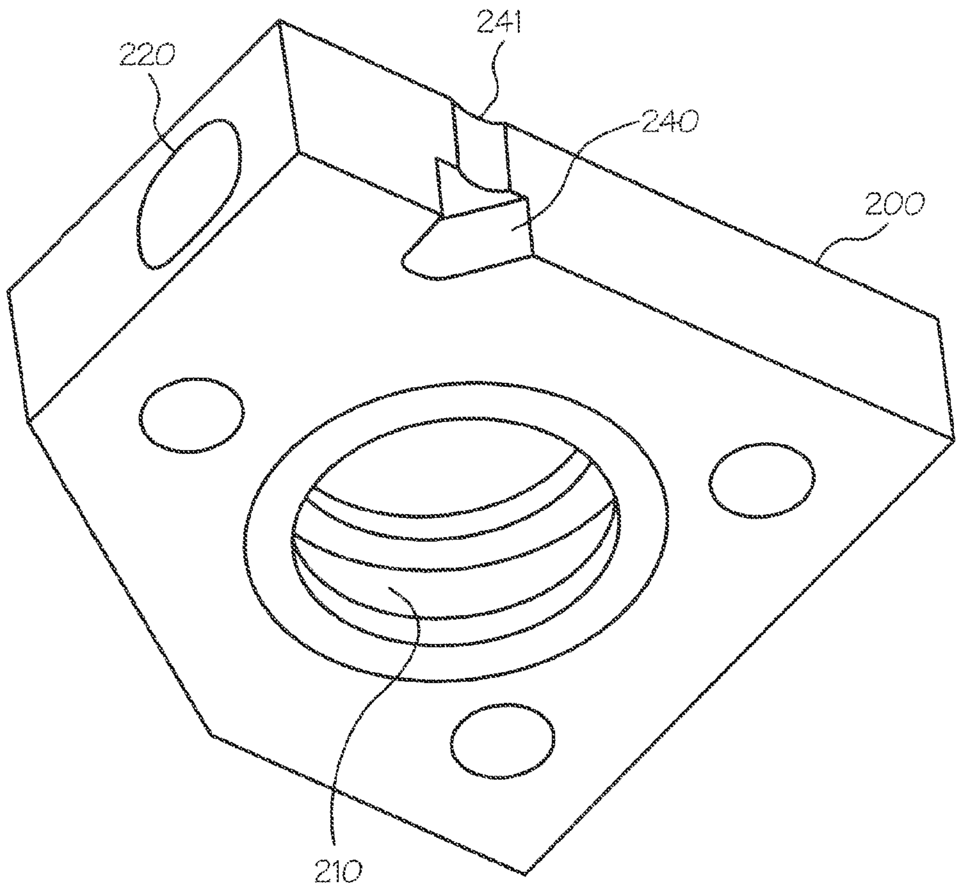

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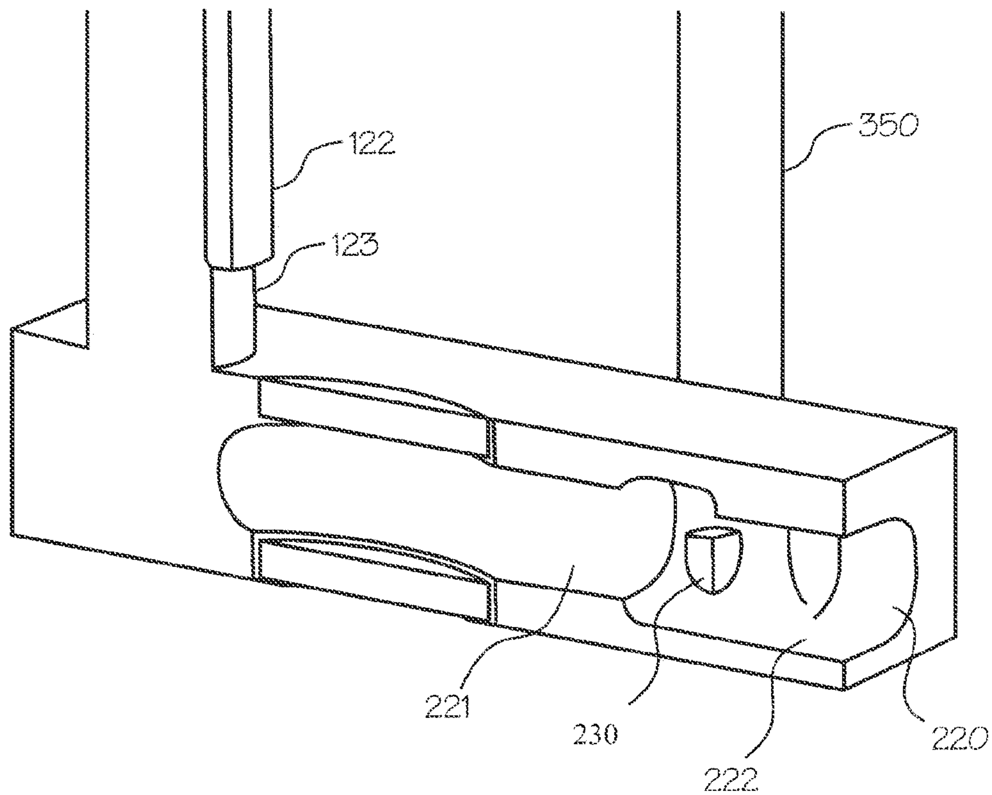

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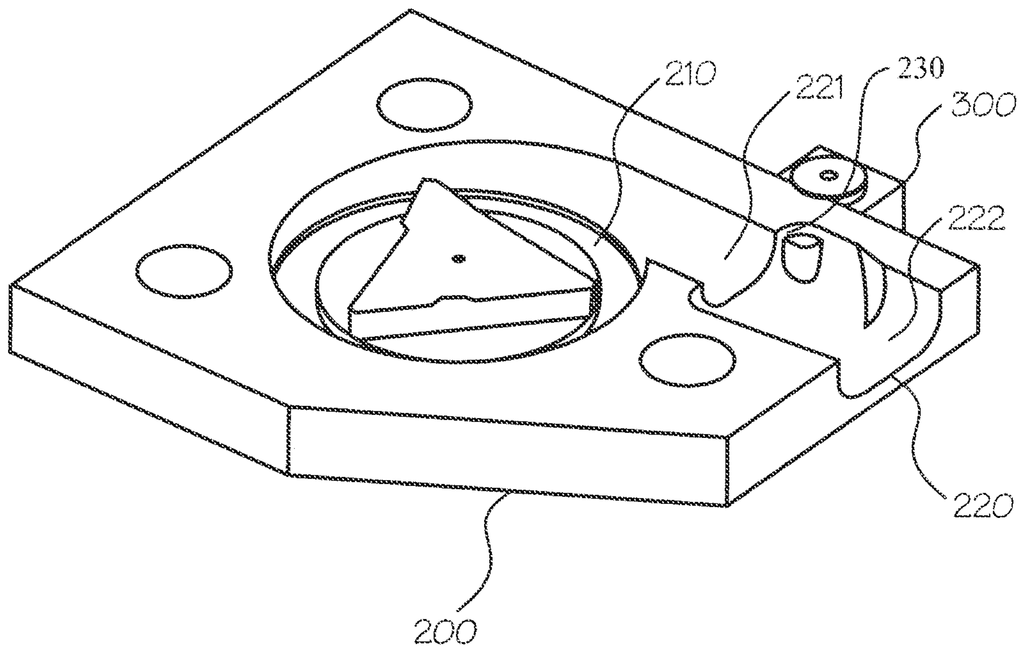

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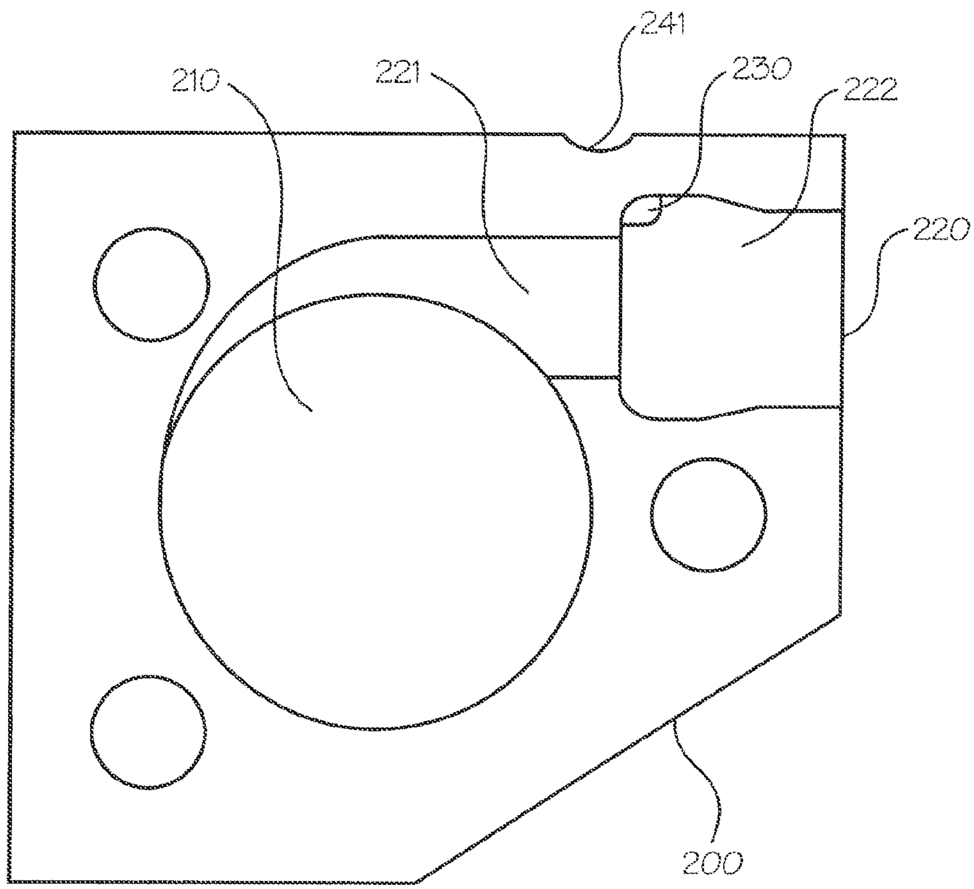

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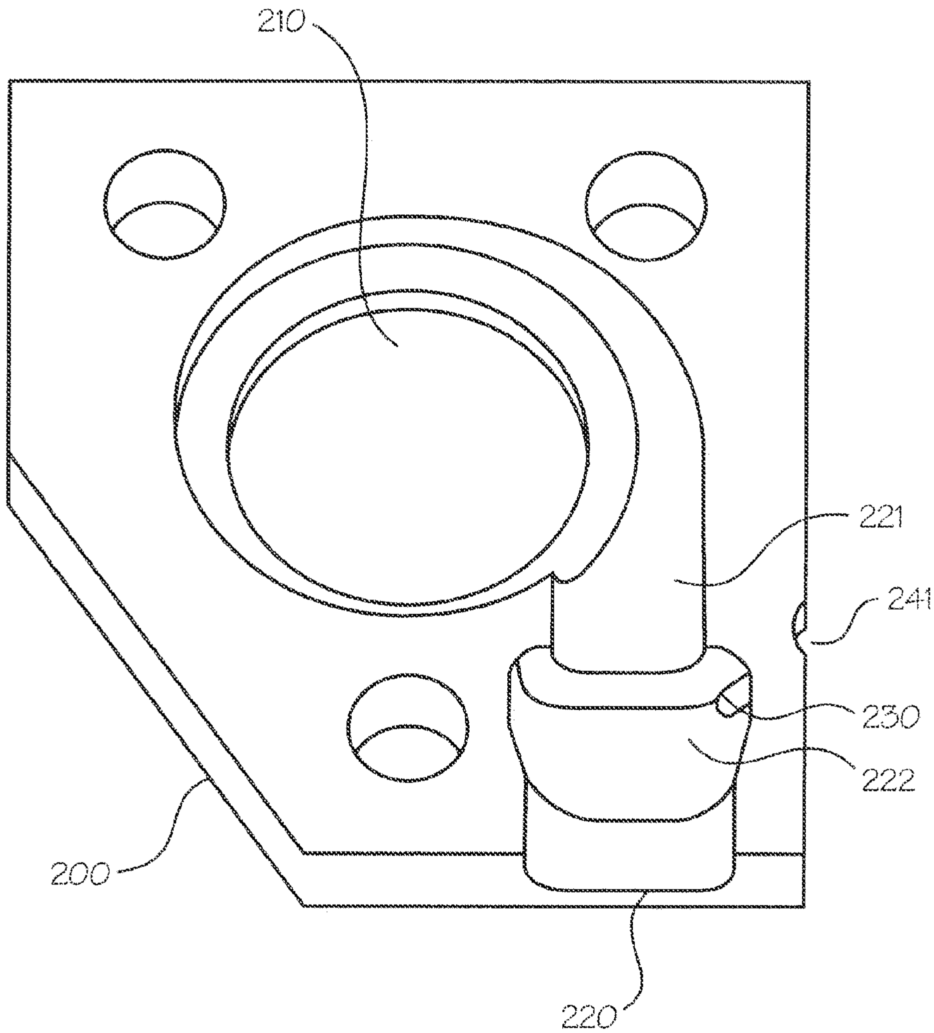

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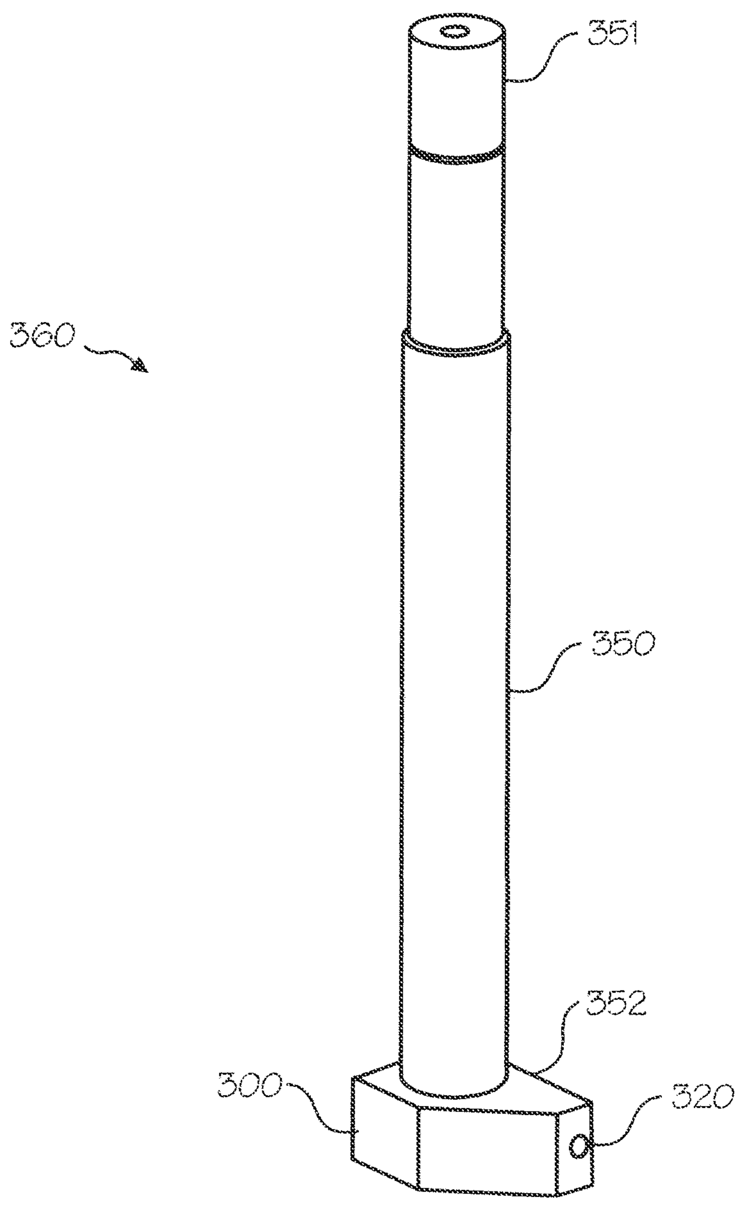

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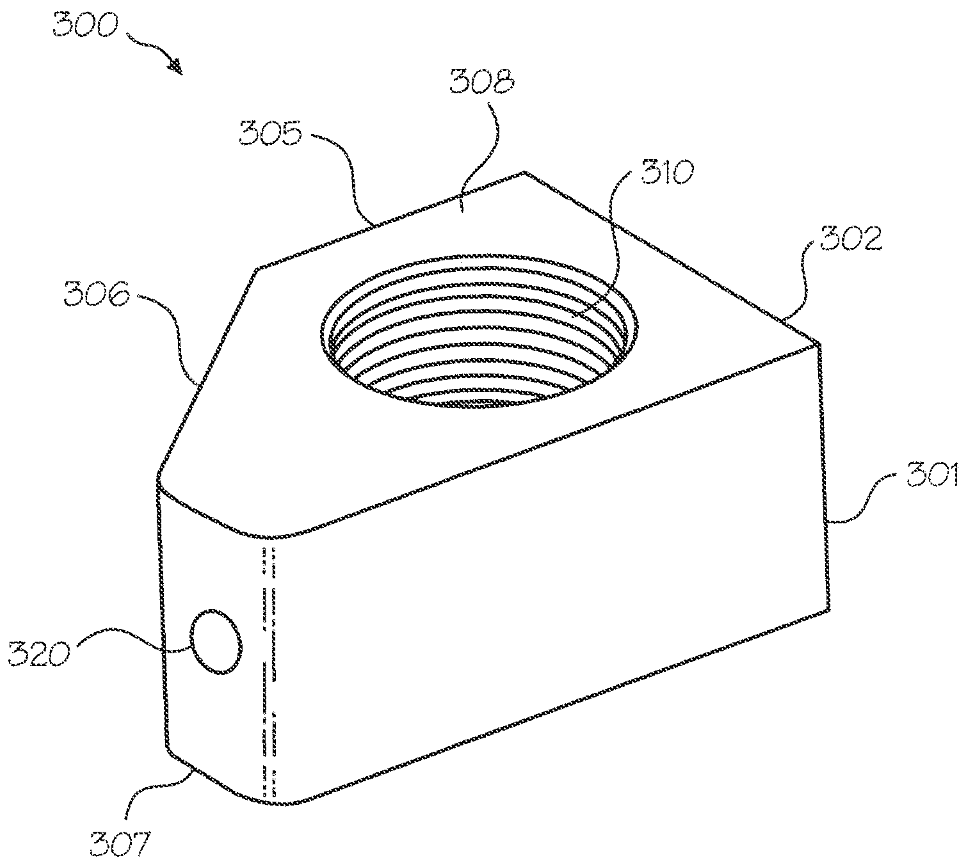

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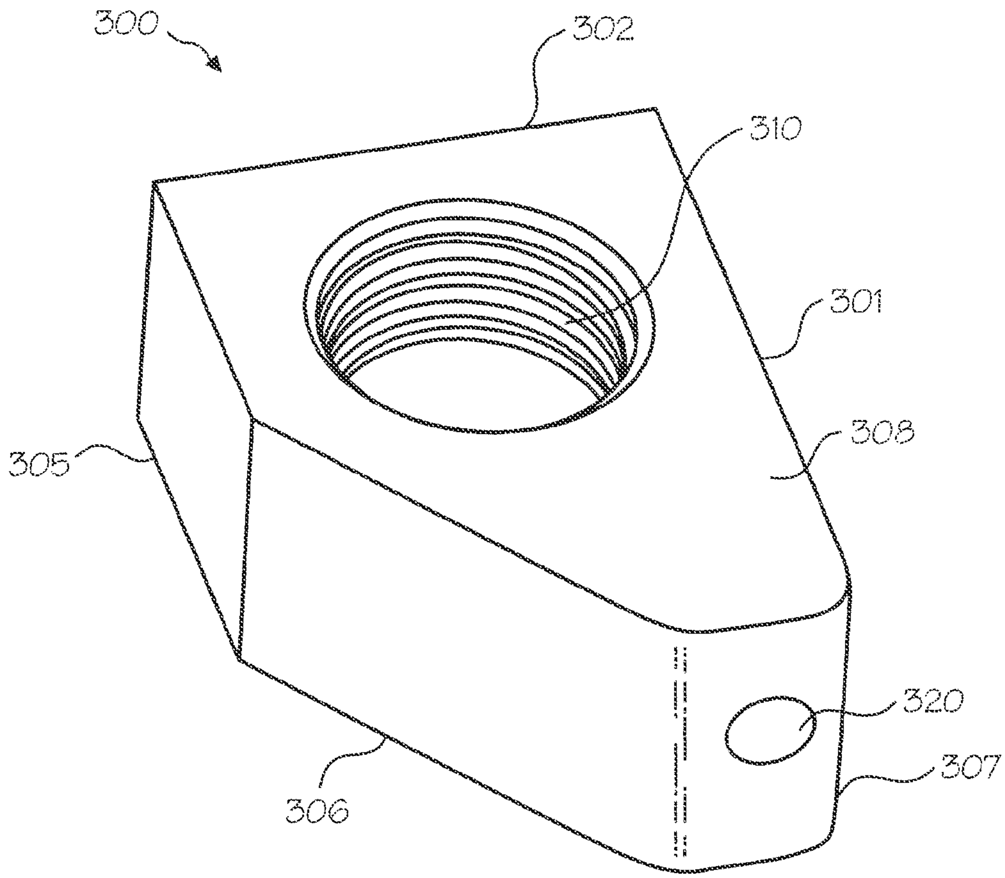

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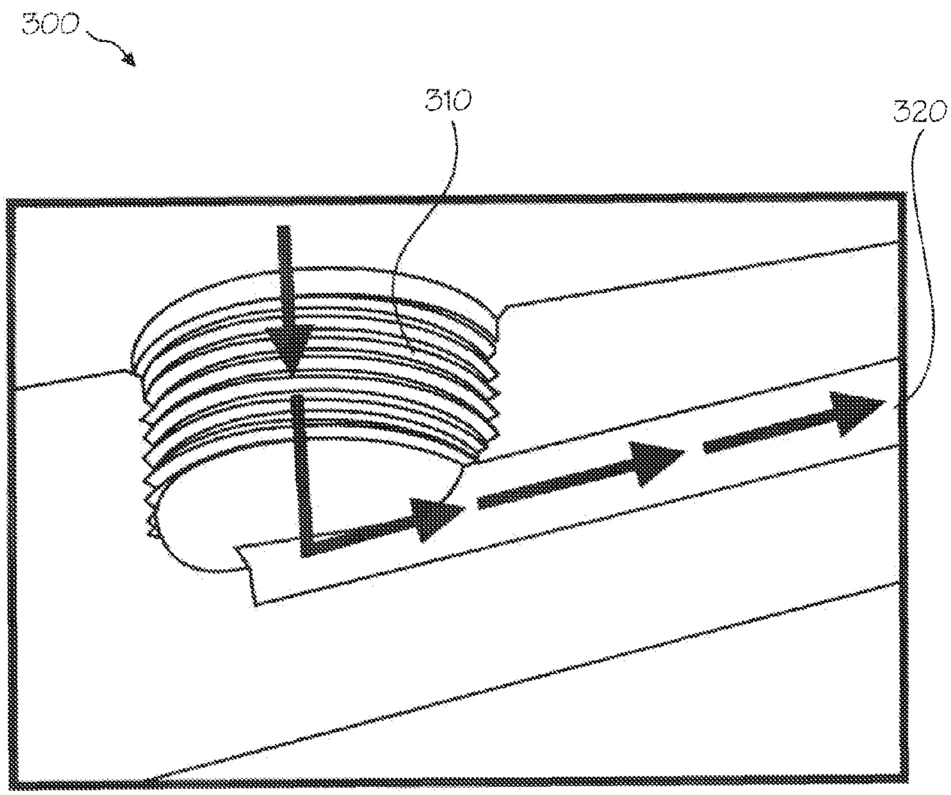

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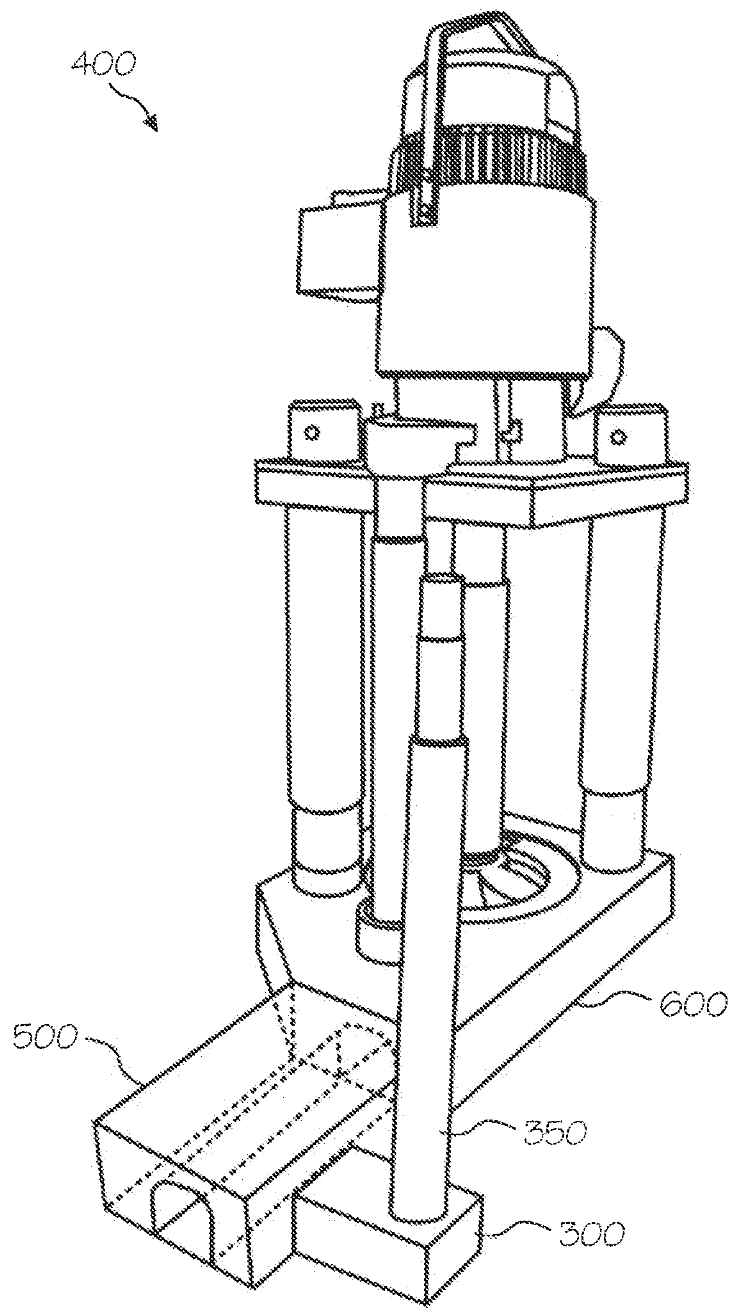

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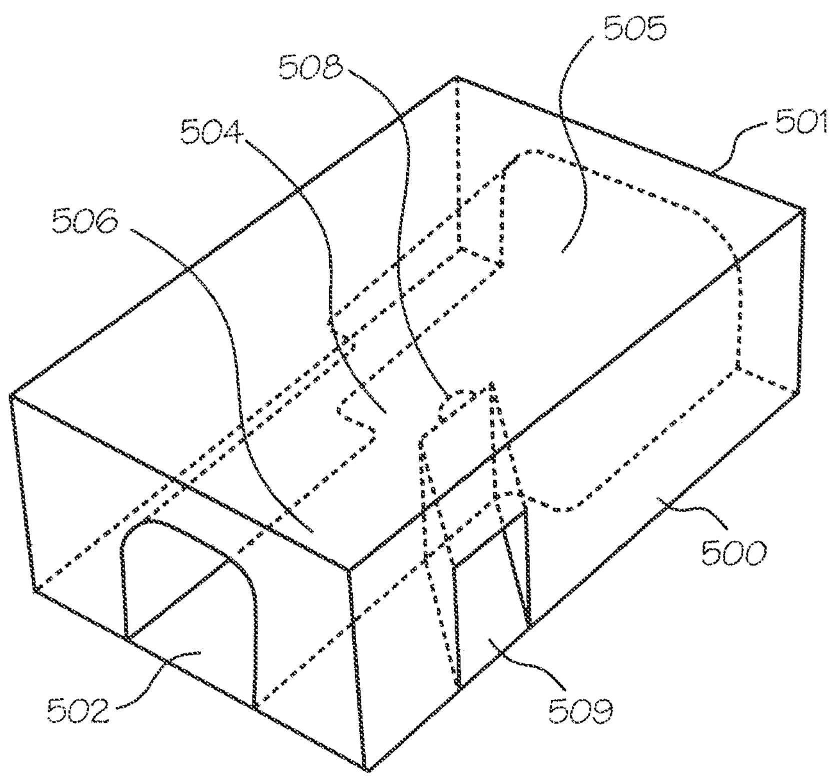

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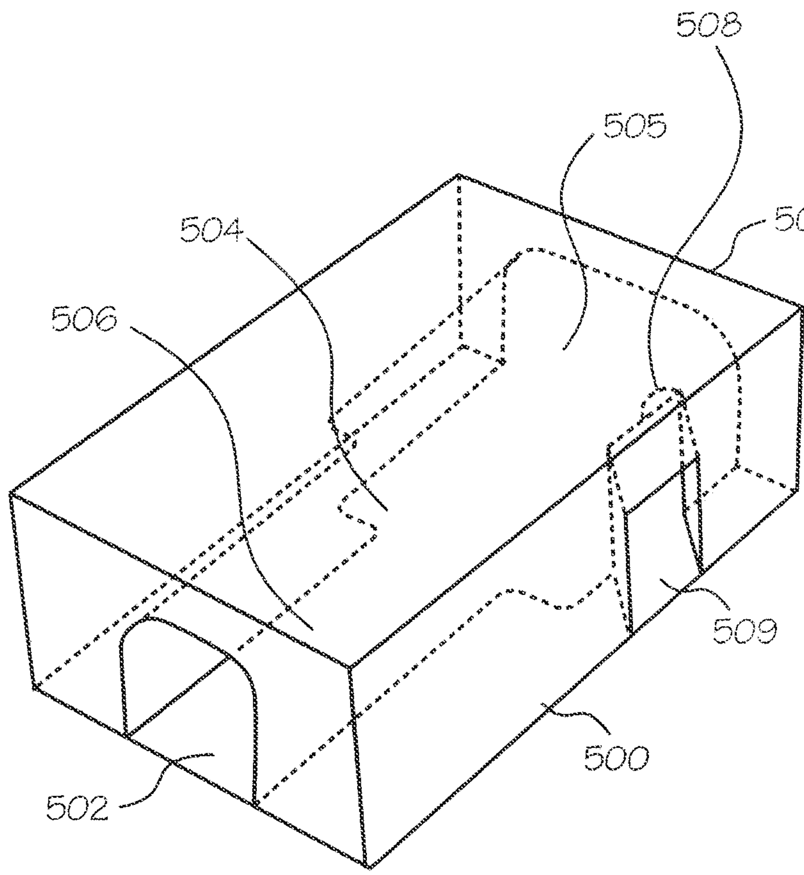

Fig. 5B

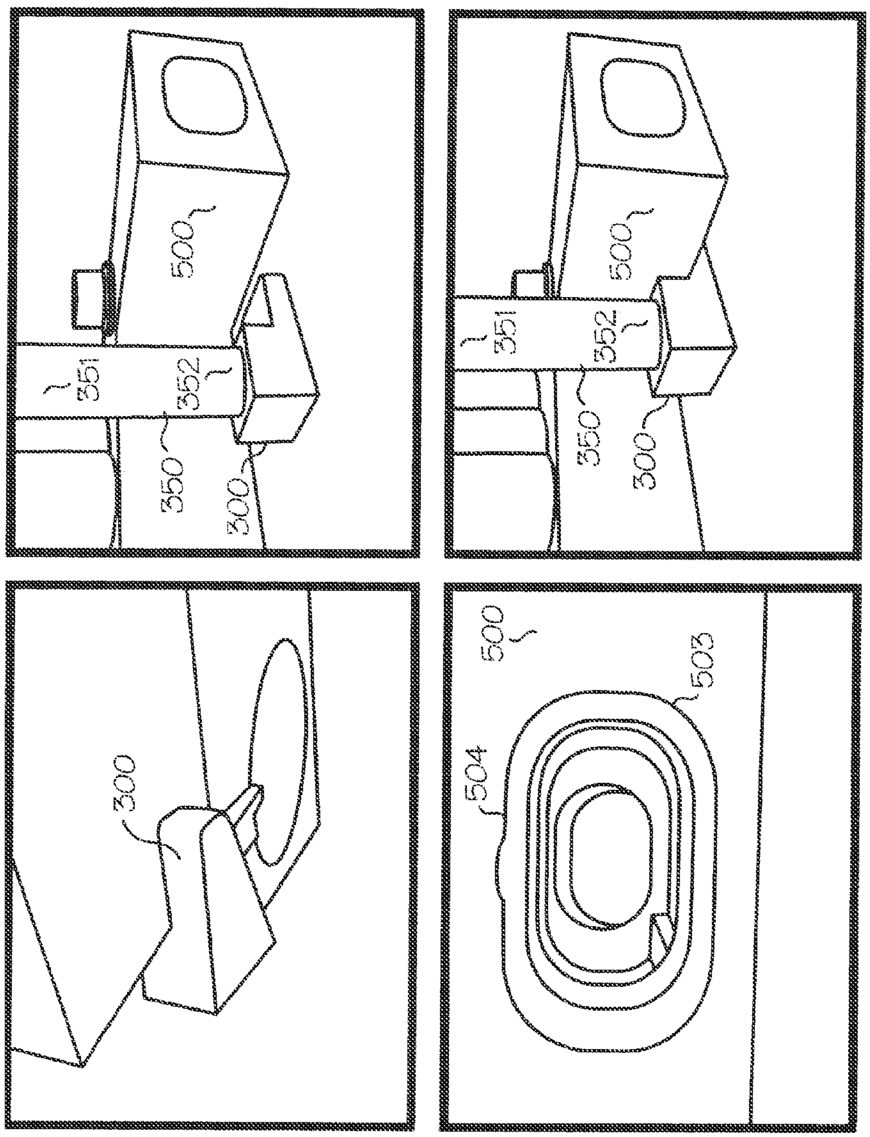

Fig. 6A

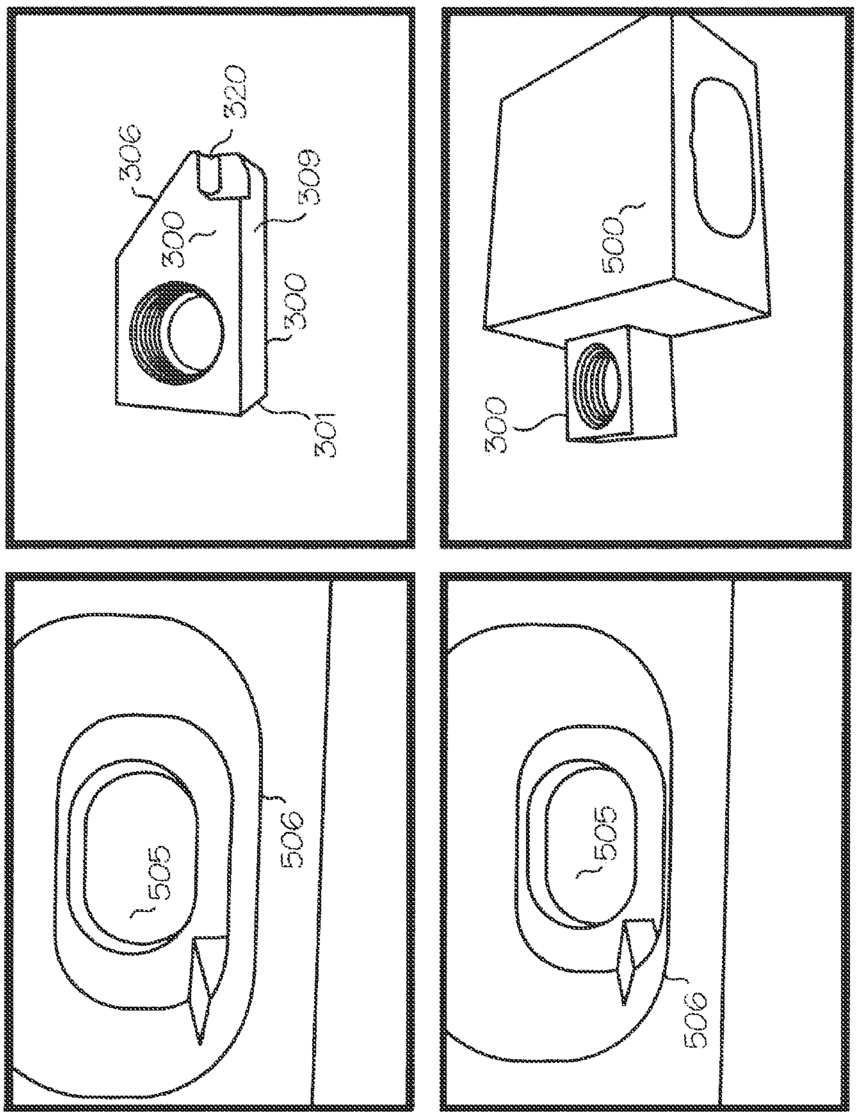

Fig. 6B

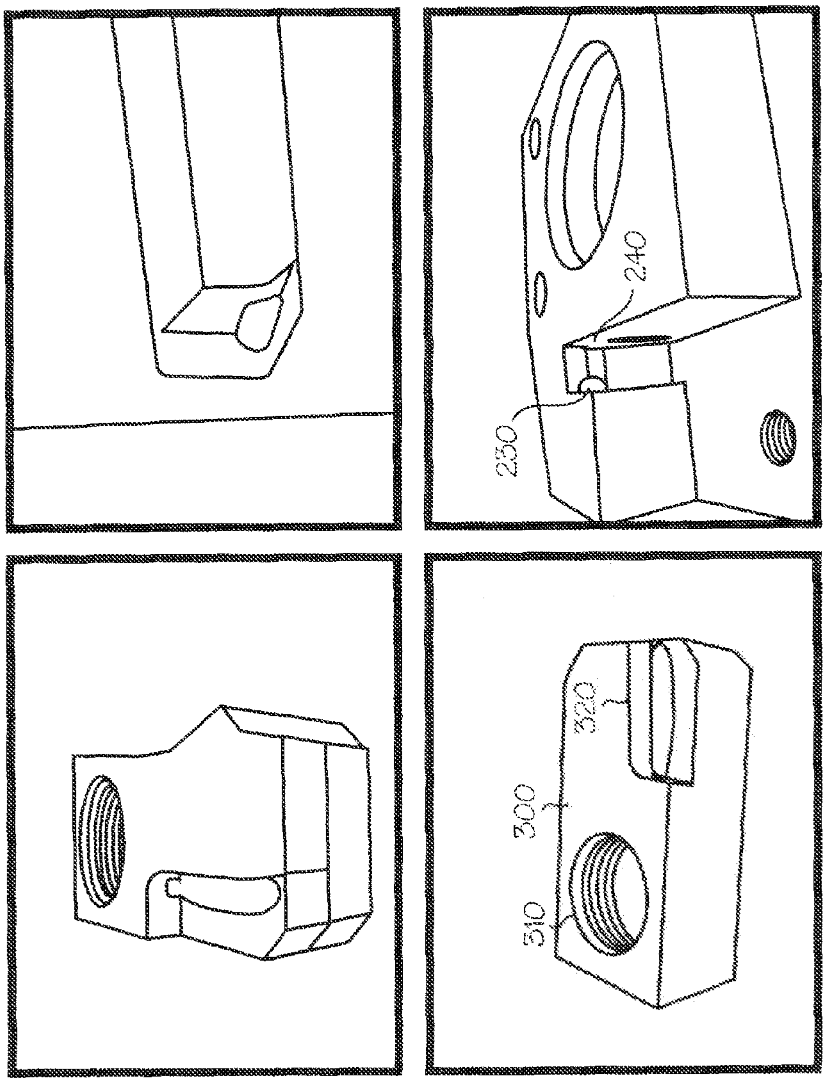

Fig. 6C

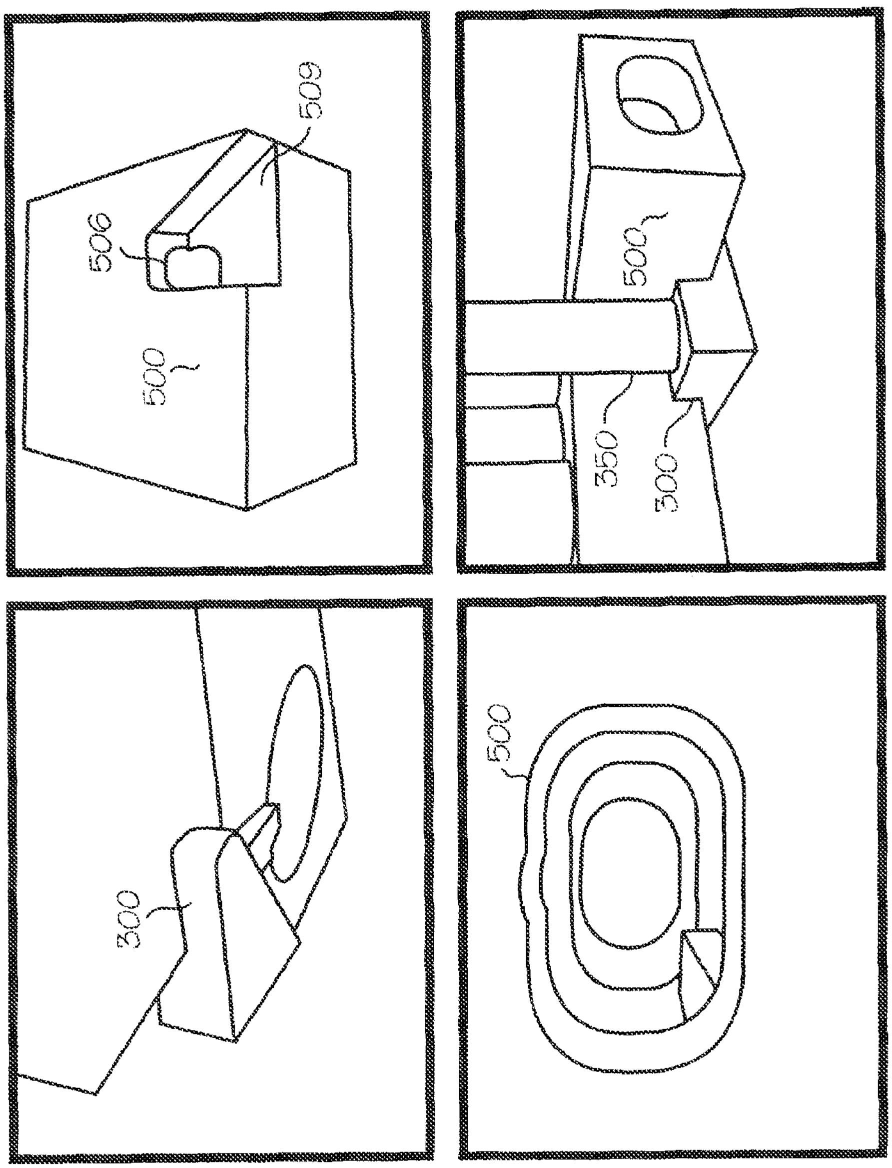

Fig. 6D

GAS-TRANSFER FOOT

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of and claims priority to U.S. application Ser. No. 13/752,312 filed Jan. 28, 2013, (Now U.S. Pat. No. 9,034,244 issued May 19, 2016), which is a continuation of and claims priority to U.S. application Ser. No. 12/395,430 filed Feb. 27, 2009, (now U.S. Pat. No. 8,361,379 issued Jan. 29, 2013), which is a continuation of and claims priority to U.S. application Ser. No. 11/413,982 filed Apr. 28, 2006 (now abandoned) and U.S. application Ser. No. 12/120,190 filed May 13, 2008, (now U.S. Pat. No. 8,178,037 issued May 15, 2012), which is a continuation of U.S. application Ser. No. 10/773,101 filed Feb. 4, 2004 (now abandoned), which is a continuation of and claims priority to U.S. application Ser. No. 10/619,405 filed Jul. 14, 2003, (now U.S. Pat. No. 7,507,367 issued Mar. 24, 2009), and U.S. application Ser. No. 10/620,318 filed Jul. 14, 2003, (now U.S. Pat. No. 7,731,891 issued Jun. 8, 2010), both of which claim priority to U.S. Provisional Patent Application Ser. No. 60/395,471, filed Jul. 12, 2002. The disclosures of each application listed herein, are incorporated herein by reference in their entirety for all purposes.

FIELD OF THE INVENTION

The invention relates to releasing gas into molten metal and more particularly, to a device for releasing gas into the bottom of a stream of molten metal that may utilize the flow of the molten metal stream to assist in drawing the gas into the stream. In this manner, the gas may be more effectively mixed into the molten metal.

BACKGROUND OF THE INVENTION

As used herein, the term “molten metal” means any metal or combination of metals in liquid form, such as aluminum, copper, iron, zinc and alloys thereof. The term “gas” means any gas or combinations of gases, including argon, nitrogen, chlorine, fluorine, Freon, and helium, which are released into molten metal.

Known pumps for pumping molten metal (also called “molten metal pumps”) include a pump base (also called a housing or casing), one or more inlets, an inlet being an opening to allow molten metal to enter a pump chamber (and is usually an opening in the pump base that communicates with the pump chamber), a pump chamber, which is an open area formed within the pump base, and a discharge, which is a channel or conduit communicating with the pump chamber (in an axial pump the pump chamber and discharge may be the same structure or different areas of the same structure) leading from the pump chamber to the molten metal bath in which the pump base is submerged. A rotor, also called an impeller, is mounted in the pump chamber and is connected to a drive shaft. The drive shaft is typically a motor shaft coupled to a rotor shaft, wherein the motor shaft has two ends, one end being connected to a motor and the other end being coupled to the rotor shaft. The rotor shaft also has two ends, wherein one end is coupled to the motor shaft and the other end is connected to the rotor. Often, the rotor shaft is comprised of graphite, the motor shaft is comprised of steel, and the two are coupled by a coupling, which is usually comprised of steel.

As the motor turns the drive shaft, the drive shaft turns the rotor and the rotor pushes molten metal out of the pump chamber, through the discharge, which may be an axial, tangential or any type of discharge, and into the molten metal bath. Most molten metal pumps are gravity fed, wherein gravity forces molten metal through the inlet (either a top inlet, bottom inlet or both) and into the pump chamber as the rotor pushes molten metal out of the pump chamber.

Molten metal pump casings and rotors usually employ a bearing system comprising ceramic rings wherein there is one or more rings on the rotor that align with rings in the pump chamber (such as rings at the inlet (which is usually at the top of the pump chamber and/or bottom of the pump chamber) when the rotor is placed in the pump chamber. The purpose of the bearing system is to reduce damage to the soft, graphite components, particularly the rotor and pump chamber wall, during pump operation. Known bearing systems are described in U.S. Pat. Nos. 5,203,681, 5,591,243 and 6,093,000 to Cooper, the respective disclosures of which are incorporated herein by reference. Further, U.S. Pat. No. 2,948,524 to Sweeney et al., U.S. Pat. No. 4,169,584 to Mangalick, U.S. Pat. No. 5,203,681 to Cooper and U.S. Pat. No. 6,123,523 to Cooper (the disclosure of U.S. Pat. No. 6,123,533 to Cooper is also incorporated herein by reference) all disclose molten metal pumps.

Furthermore, copending U.S. patent application Ser. No. 10/773,102 to Cooper, filed on Feb. 4, 2004 and entitled “Pump With Rotating Inlet” discloses, among other things, a pump having an inlet and rotor structure (or other displacement structure) that rotate together as the pump operates in order to alleviate jamming. The disclosure of this copending application is incorporated herein by reference.

The materials forming the components that contact the molten metal bath should remain relatively stable in the bath. Structural refractory materials, such as graphite or ceramics, that are resistant to disintegration by corrosive attack from the molten metal may be used. As used herein “ceramics” or “ceramic” refers to any oxidized metal (including silicon) or carbon-based material, excluding graphite, capable of being used in the environment of a molten metal bath. “Graphite” means any type of graphite, whether or not chemically treated. Graphite is particularly suitable for being formed into pump components because it is (a) soft and relatively easy to machine, (b) not as brittle as ceramics and less prone to breakage, and (c) less expensive than ceramics.

Three basic types of pumps for pumping molten metal, such as molten aluminum, are utilized: circulation pumps, transfer pumps and gas-release pumps. Circulation pumps are used to circulate the molten metal within a bath, thereby generally equalizing the temperature of the molten metal. Most often, circulation pumps are used in a reverbatory furnace having an external well. The well is usually an extension of a charging well where scrap metal is charged (i.e., added).

Transfer pumps are generally used to transfer molten metal from the external well of a reverbatory furnace to a different location such as a ladle or another furnace. Examples of transfer pumps are disclosed in U.S. Pat. No. 6,345,964 B1 to Cooper, the disclosure of which is incorporated herein by reference, and U.S. Pat. No. 5,203,681.

Gas-release pumps, such as gas-transfer pumps, circulate molten metal while releasing a gas into the molten metal. In the purification of molten metals, particularly aluminum, it is frequently desired to remove dissolved gases such as hydrogen, or dissolved metals, such as magnesium, from the molten metal. As is known by those skilled in the art, the removing of dissolved gas is known as “degassing” while the removal of magnesium is known as “demagging.” Gas-release pumps may be used for either of these purposes or for any other application for which it is desirable to introduce gas into molten metal. Gas-release pumps generally include a gas-transfer conduit having a first end that is connected to a gas source and a second submerged in the molten metal bath. Gas is introduced into the first end and is released from the second end into the molten metal. The gas may be released downstream of the pump chamber into either the pump discharge or a metal-transfer conduit extending from the discharge, or into a stream of molten metal exiting either the discharge or the metal-transfer conduit. Alternatively, gas may be released into the pump chamber or upstream of the pump chamber at a position where it enters the pump chamber. A system for releasing gas into a pump chamber is disclosed in U.S. Pat. No. 6,123,523 to Cooper, and in copending U.S. application Ser. No. 10/773,101 entitled System for Releasing Gas Into Molten Metal filed on Feb. 4, 2004.

The advantage of a system for releasing gas into molten metal within the confines of a metal-transfer conduit is that the gas and metal should have a better opportunity to thoroughly interact. One problem with releasing gas into a metal-transfer conduit is that, in some systems, the conduit (called a gas-transfer conduit) that transfers the gas from a gas source into the molten metal stream typically extends into the metal-transfer conduit, usually extending downward from the top of the metal-transfer conduit, and disrupts the flow of molten metal passing through the conduit and creating a low-pressure area behind the portion of the gas-transfer conduit extending into the metal-transfer conduit. The low-pressure area can interfere with the released gas mixing with molten metal passing through the metal-transfer conduit because, among other things, the gas immediately rises into the low-pressure area instead of mixing with molten metal throughout the metal-transfer conduit. This can create a phenomenon known as "burping" because a large gas bubble will build up in the low pressure area and then be released from the discharge instead of thoroughly mixing with the molten metal.

SUMMARY OF THE INVENTION

The present invention includes a molten metal pump that enables gas to be released into a stream of molten metal so that the gas is mixed into the molten metal stream. The gas may be released into an enclosed molten metal stream at location(s) within the pump assembly, including at a stream within the pump discharge and/or a stream within a metal-transfer conduit extending from the pump discharge. The gas is released by a structure called a "gas-transfer foot." The gas-transfer foot is positioned next to and/or is attachable to the pump base and/or a metal-transfer conduit extending from the pump base.

The discharge (pump base) and/or channel (metal-transfer conduit) in which the gas is released may be comprised of two sections: a first section having a first cross-sectional area and a second section downstream from the first section having a second cross-sectional area that is larger than the first cross-sectional area. Preferably, the gas is released into or near the second section so that the gas is released into an area of relatively lower pressure.

The gas-transfer foot preferably includes a gas inlet port through which gas enters the foot and a gas outlet port through which gas exits the foot. The gas-transfer foot may be configured to be attachable to a pump base and/or metal-transfer conduit such that gas exiting the outlet port can enter the bottom of a stream of molten metal. The gas-transfer foot is preferably coupled to a gas-transfer tube to form a gas-transfer assembly. The gas-transfer tube includes a first end connectable to the inlet port of the foot and a second end connectable to a gas source.

For example, the gas-transfer foot may be attachable to a base of a molten metal pump. In that case the gas-release opening is preferably on the bottom surface of the discharge that is in communication with either the first section, the second section, or both the first and second sections.

The gas-transfer foot may also be attachable to a metal-transfer conduit, which may extend form the pump discharge. The metal-transfer conduit includes an inlet port, an outlet port, a conduit, and a gas-release opening. The inlet port is in communication with the base discharge. The outlet port is downstream from the inlet port and is connected to the inlet port via the conduit. The conduit preferably has a bottom surface and includes a first section having a first cross-sectional area and a second section having a second cross-sectional area. The second section is downstream of the first section and the second cross-sectional area is greater than the first cross-sectional area. The opening is preferably positioned on the bottom surface of the metal-transfer conduit and is in communication with either the first section, the second section, or both the first and second sections. The gas outlet port of the foot is in communication with the opening in the metal so that gas can be transferred from the gas outlet port through the opening and into the conduit.

The base of the molten metal pump configured to receive a gas-transfer foot according to the invention. Such a base includes a gas-transfer foot notch or ("notch") to receive the foot and position it such that the gas exiting the gas-release opening in the foot enters the molten metal stream in the pump base. The opening is preferably on the bottom surface of the discharge and enables gas to enter the bottom of the discharge. The notch is preferably constructed so that gas-transfer foot is positioned so that gas exiting the outlet port enters a relatively lower pressure section of the molten metal stream.

The metal-transfer conduit may be configured to receive a gas-transfer foot. The notch is preferably constructed so that the gas outlet port of a gas-transfer foot is in communication with the gas-release opening when the gas-transfer foot is inserted into the notch.

Both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A depicts a molten metal pump according to one embodiment of the invention.

FIG. **1**B depicts a three support post variation of the molten metal pump shown in FIG. **1**A.

FIG. **1**C depicts a bottom isometric view of a molten metal pump according to one embodiment of the invention.

FIG. **2**A depicts an isometric view of a base for a molten metal pump according to one embodiment of the invention.

FIG. **2**B depicts the discharge of a molten metal pump base according to one embodiment of the invention.

FIG. **2**C depicts a top isometric view of a pump base with a gas-transfer foot notch according to one embodiment of the invention.

FIG. **2**D depicts a bottom isometric view of a pump base with a gas-transfer foot notch according to one embodiment of the invention.

FIG. 2E depicts a vertical cross-sectional view of a pump base and attached gas-transfer assembly according to one embodiment of the invention.

FIG. 2F depicts a horizontal cross-sectional view of a pump base and attached gas-transfer foot according to one embodiment of the invention.

FIG. 2G depicts a top-down horizontal cross-sectional view of a pump base according to one embodiment of the invention.

FIG. 2H depicts an isometric horizontal cross-sectional view of a pump base according to one embodiment of the invention.

FIG. 3A depicts a gas-transfer assembly according to one embodiment of the invention.

FIG. 3B depicts an isometric view of a gas-transfer foot according to one embodiment of the invention.

FIG. 3C depicts another isometric view of a gas-transfer foot according to one embodiment of the invention.

FIG. 3D depicts a vertical cross-sectional view of a gas-transfer foot according to one embodiment of the invention.

FIG. 4 is another embodiment of a molten metal pump according to the invention.

FIG. 5A is an embodiment of a metal-transfer conduit according to the present invention.

FIG. 5B is another embodiment of a metal-transfer conduit according to the present invention.

FIGS. 6A-D show photographs of other views of metal-transfer conduits and gas-transfer assemblies according to various aspects of the invention

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference will now be made in detail to the present exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. FIG. 1A depicts a molten metal pump **100** according to the invention. When in operation, pump **100** is typically positioned in a molten metal bath in a pump well, which is typically part of the open well of a reverbatory furnace. Pump **100** includes motor **120**, superstructure **130**, support posts **132**, drive shaft **122**, rotor **110**, base **200**, gas-transfer foot **300** and gas-transfer tube **350**.

The components of pump **100** that are exposed to the molten metal (such as support posts **132**, drive shaft **122**, rotor **110**, base **200**, gas-transfer foot **300** and gas-transfer tube **350**) are preferably formed of structural refractory materials, which are resistant to degradation in the molten metal. Carbonaceous refractory materials, such as carbon of a dense or structural type, including graphite, graphitized carbon, clay-bonded graphite, carbon-bonded graphite, or the like have all been found to be most suitable because of cost and ease of machining. Such components may be made by mixing ground graphite with a fine clay binder, forming the non-coated component and baking, and may be glazed or unglazed. In addition, components made of carbonaceous refractory materials may be treated with one or more chemicals to make the components more resistant to oxidation. Oxidation and erosion treatment for graphite parts are practiced commercially, and graphite so treated can be obtained from sources known to those skilled in the art.

Pump **100** need not be limited to the structure depicted in FIG. 1A, but can be any structure or device for pumping or otherwise conveying molten metal, such as the pump disclosed in U.S. Pat. No. 5,203,681 to Cooper, or an axial pump having an axial, rather than tangential, discharge. Preferred pump **100** has a pump base **200** for being submersed in a molten metal bath. Pump base **200** preferably includes a generally nonvolute pump chamber **210**, such as a cylindrical pump chamber or what has been called a "cut" volute, although pump base **200** may have any shape pump chamber suitable of being used, including a volute-shaped chamber. Chamber **210** may be constructed to have only one opening, either in its top or bottom, if a tangential discharge is used, since only one opening is required to introduce molten metal into pump chamber **210**. Generally, pump chamber **210** has two coaxial openings of the same diameter and usually one is blocked by a flow blocking plate mounted on, or formed as part of, rotor **110**. Base **200** further includes a tangential discharge **220** (although another type of discharge, such as an axial discharge may be used) in fluid communication with chamber **210**. Base **200** will be described in more detail below with reference to FIGS. 2A and 2B.

One or more support posts **132** connect base **200** to a superstructure **130** of pump **100** thus supporting superstructure **130**, although any structure or structures capable of supporting superstructure **130** may be used. Additionally, pump **100** could be constructed so there is no physical connection between the base and the superstructure, wherein the superstructure is independently supported. The motor, drive shaft and rotor could be suspended without a superstructure, wherein they are supported, directly or indirectly, to a structure independent of the pump base.

In the preferred embodiment, post clamps **133** secure posts **132** to superstructure **130**. A preferred post clamp and preferred support posts are disclosed in a copending U.S. application Ser. No. 10/773,118 entitled "Support Post System For Molten Metal Pump," invented by Paul V. Cooper, and filed on Feb. 4, 2004, the disclosure of which is incorporated herein by reference. However, any system or device for securing posts to superstructure **130** may be used.

A motor **120**, which can be any structure, system or device suitable for driving pump **100**, but is preferably an electric or pneumatic motor, is positioned on superstructure **130** and is connected to an end of a drive shaft **122**. A drive shaft **122** can be any structure suitable for rotating an impeller, and preferably comprises a motor shaft (not shown) coupled to a rotor shaft. The motor shaft has a first end and a second end, wherein the first end of the motor shaft connects to motor **120** and the second end of the motor shaft connects to the coupling. Rotor shaft **123** has a first end and a second end, wherein the first end is connected to the coupling and the second end is connected to rotor **110** or to an impeller according to the invention. A preferred coupling, rotor shaft and connection between the rotor shaft and rotor **110** are disclosed in a copending application entitled "Molten Metal Pump Components," invented by Paul V. Cooper and filed on Feb. 4, 2004, the disclosure of which is incorporated herein by reference.

The preferred rotor **110** is disclosed in a copending U.S. patent application Ser. No. 10/773,102 to Cooper, filed on Feb. 4, 2004 and entitled "Pump With Rotating Inlet", the disclosure of which is incorporated herein by reference. However, rotor **110** can be any rotor suitable for use in a molten metal pump and the term "rotor," as used in connection with this invention, means any device or rotor used in a molten metal pump chamber to displace molten metal.

Gas-transfer foot **300** and gas-transfer tube **350** combined forms a gas transfer assembly **360**. Gas-transfer foot **300** is positioned next to (and may be attachable to) base **200** so that a gas outlet port **320** (shown in FIG. 1B) of the gas-transfer foot is in communication with a gas-release opening (not shown in FIG. 1A) in the base. Gas is fed into the gas source end of gas-transfer tube **350** which flows into the gas-transfer foot and then into the flow of molten metal within base **200**.

FIG. **1**B depicts a variation of the molten metal pump shown in FIG. **1**A. The molten metal pump in FIG. **1**B has three support posts **132** rather than five. FIG. **1**B also depicts the gas-releasing opening **320** of gas-transfer foot **300** when the gas-transfer foot **300** is positioned next to and/or attached to base **200**.

As shown in FIG. **1**C, gas-transfer foot **300** may be positioned next to molten metal pump **100** by inserting into a notch **214** constructed in base **200**. In this way, the weight of the pump holds the gas-transfer foot in place. Methods for positioning, securing and/or attaching the gas-transfer foot next to the base need not be limited to the notch shown in FIG. **1**C. All that is needed is a gas-transfer foot that may be positioned next to a molten metal pump base such that gas flowing through the foot may enter into a stream of molten metal flowing through the pump base and/or or a conduit extending from the pump base.

FIG. **2**A depicts an isometric view of a base for a molten metal pump according to one embodiment of the invention. Base **200** has a top surface **218**, a bottom surface **219**, a first side **212**, a second side **214**, a third side **215**, a fourth side **216**, and a fifth side **217**. The base need not be constructed with five sides, but may be of any shape. Base **200** further includes one or more (and preferably three) cavities **202**, **204** and **206** for receiving support posts **132**. The cavities connect base **200** to support posts **132** such that support posts **132** can support superstructure **130**, and can help to support the weight of base **200** when pump **100** is removed from a molten metal bath. Any structure suitable for this purpose may be used.

Base **200** also includes a discharge **220** that is in fluid communication with chamber **210**. A notch **214** allows for the gas-transfer foot to be positioned next to the pump base. When in position the gas-release opening of the gas-transfer foot is in fluid communication with gas-release opening **230** such that gas may introduced into a stream of molten metal traveling through discharge **220**.

As shown in FIG. **2**B, discharge **220** has at least two sections wherein at least one section (a first section) has a smaller cross-sectional area than at least one other section (a second section) downstream of the first section. Here, a first section **221** has a first cross-sectional area and a second section **222** is downstream of first section **32** and has a second cross-sectional area.

Section **221** is preferably about 1" in length, 3" in height and 4½" in width for a pump utilizing a 10" diameter rotor, and has a substantially flat top surface **221**A, a substantially flat bottom surface **221**B, a first radiused side surface **221**C and a second radiused side surface **221**D. Section **221** defines a passage through which molten metal may pass, and any shape or size passage suitable for efficiently conveying molten metal may be used.

Second section **222** is preferably 10" in length (although any suitable length may be utilized) and has a top surface **222**A (shown in FIG. **2**A), a bottom surface **222**B, a first side surface **222**C and second side surface **222**D. Section **222** defines a passage through which molten metal passes and any shape or size passage suitable for efficiently conveying molten metal may be used. Section **222** preferably has a height of about 4" and width of about 5½" for a pump utilizing a rotor with a diameter of 10". Section **222** has a height of about 4" and width of about 6½" for a pump utilizing a rotor having a diameter of 16", and preferably has a cross-sectional area between about 110% and 350% larger than the cross-sectional area of section **221**. However, all that is necessary for the proper functioning of the invention is that the cross-sectional area of section **222** be sufficiently larger than the area of section **221** to reduce the amount of pressure required for gas to be released into the molten metal stream as compared to the pressure required to release gas into a metal-transfer conduit that has substantially the same cross-sectional area throughout.

Alternatively, discharge **220** or any metal-transfer conduit in accordance with the invention could have multiple cross-sectional areas, as long as there is a transition from a first section with a first cross-sectional area to a second section with a second cross-sectional area, wherein the second section is downstream of the first section and the second cross-sectional area is greater than the first cross-sectional area. It is preferred that there be an abrupt transition from the first section having a first cross-sectional area to a second section having a second, larger cross-sectional area, however, the transition may be somewhat gradual, taking place over a length of up to 6" or more.

Preferably, a gas-release opening **230** is formed in second section **222** through bottom surface **219** of base **200**. However, gas-release opening **230** may also be formed in a top or side section of base **200**. Gas-release opening **230** is any size suitable for releasing gas from an opening in gas-transfer foot **300** into discharge **220**. It is preferred that gas-release opening **230** be formed outside of the higher-pressure flow of the molten metal stream (such as in section **222**), but it can be positioned anywhere suitable for releasing gas into discharge **220**. For example, as shown in FIG. **2**B gas-release opening **230** may be formed in second section **222** near (preferably within 3") first section **221**. However, all that is necessary for the proper functioning of the invention is that there be (1) a first section for transferring a molten metal stream having a first cross-sectional area and a second section downstream of the first section, wherein the second section has a second cross-sectional area larger than the first section, and (2) a gas-release opening in the first section and/or the second section (preferably in or near the bottom surface of either section), whereby the respective sections are configured and the gas-release openings is positioned so that less pressure is required to release gas into the molten metal than would be required in known metal-transfer conduits that have substantially the same cross-sectional area throughout. Thus, in addition to a gas-release opening being formed in the first section or the second section, a gas-release opening could be formed in the first section and another gas-release opening could be formed in the second section, and gas could be released into each section, or into one section or the other.

FIGS. **2**C and **2**D show gas-transfer foot notch **240** for attachment of a gas-transfer foot. The notch is shaped so as to accept the gas-transfer foot **300** (described below) and is preferably positioned in the bottom surface of base **200** so that the weight of the base secures gas-transfer foot **300** when it is inserted into notch **240**. Though not required, the gas-transfer foot may be cemented in place or otherwise secured to the base in any suitable manner. As shown, notch **240** includes one angled side to accept a gas-transfer foot with an angled side. However, any shape notch is suitable as long as it is configured to properly position the gas-transfer foot so that gas released from the gas-release opening of the gas-transfers enters into the molten metal stream when the gas-transfer foot is inserted into the notch. In addition, pump base **200** may also include a tube notch **241** so that gas-transfer tube **350** may be positioned closer to pump base **200** and be held more firmly in place.

FIGS. **2**E-F show cross-sectional views of a pump base with and without an attached gas-transfer foot. FIG. **2**E depicts a vertical cross-sectional view of a pump base and attached gas-transfer assembly. FIG. **2**F depicts a horizontal cross-sectional view of a pump base and attached gas-transfer foot. FIG. **2**G depicts a top-down horizontal cross-sectional view of a pump base. FIG. **2**H depicts an isometric horizontal cross-sectional view of a pump base.

FIG. **3** depicts a gas-transfer assembly **360** according to the invention. The gas-transfer assembly **360** includes gas-transfer foot **300** and gas-transfer tube **350**. Gas-transfer foot **300** includes a gas outlet port **320** which is in fluid communication with gas-release opening **230** (see FIGS. **2**A-H) when the foot is positioned next to and/or attached to the base. The gas outlet port may be any size that allows for the release of gas into a stream of molten metal, and is preferably at least ½ inch in diameter.

Gas-transfer tube **350** is preferably a cylindrical, graphite tube having a first end **351** (connectable to a gas source) and a second end **352** (for connecting to the gas-transfer foot) and a passage extending therethrough. Preferably second end **352** is threaded so as to provide a secure fit into the threaded hole of gas inlet port **310**. However, any structure capable of transferring gas from a gas source (not shown) to gas-transfer foot according to the invention may be used.

As depicted in FIGS. **3**B and **3**C, gas-transfer foot **300** has a top surface **308**, a bottom surface **310**, and sides **301**, **302**, **305**, **306** and **307**. As shown, side **306** is angled so as to fit into notch **240** as described above. However, the gas-transfer foot need not be shaped as depicted (it could have more or fewer sides and be of any suitable shape), but preferably is shaped so that it is received into a notch in the base of a molten metal pump or metal-transfer conduit to be positioned such that gas released from the foot passes into the molten metal stream in either the base or metal-transfer conduit. Gas-transfer foot **300** also includes gas inlet port **310** through which gas enters the foot from gas-transfer tube **350**. In this embodiment, gas inlet port **310** is shown to be threaded to accept a threaded end of gas-transfer tube **350**. However, any method for attaching the gas-transfer tube to the gas-transfer foot may be used so long as gas is able to flow from the tube into the foot.

As shown in FIG. **3**D, gas inlet port **310** is in fluid communication with gas outlet port **320**. Gas inlet port **310** may be of any size that allows for connection with gas-transfer tube **350**, and is preferably at least a ½ inch diameter opening.

FIG. **4** depicts a molten metal pump according to a second embodiment of the invention. In this embodiment pump **400** includes a metal-transfer conduit **500** and a base **600**. The remaining components are the same as described above with reference to pump **100**. In this embodiment, metal-transfer conduit **500** is in communication with the discharge of base **600** so that the stream of molten metal flows through the conduit. A gas-transfer foot is insertable into the metal-transfer conduit so that gas is released into the bottom of the stream of molten metal within the conduit.

Base **600** is similar to base **400** except that base **600** need not have a gas-release opening or a gas-transfer foot notch. However, a base with a gas-release opening and notch in which a gas-transfer foot is inserted may be used in conjunction with the metal-transfer conduit so that gas may be released into the steam of molten metal at both the base and the conduit.

FIG. **5**A depicts a metal-transfer conduit according to the invention. Metal-transfer conduit **500** includes inlet port **501** and outlet **502**. The inlet port and outlet port are in fluid communication via conduit path **504**. Conduit path **504** has at least two sections wherein at least one section (a first section) has a smaller cross-sectional area than at least one other section (a second section) downstream of the first section. Here, a first section **506** has a first cross-sectional area and a second section **505** is downstream of first section **506** and has a second cross-sectional area.

Section **506** is preferably about 1" in length, 3" in height and 4½" in width for a pump utilizing a 10" diameter rotor, and has a substantially flat top surface, a substantially flat bottom surface, a first radiused side surface and a second radiused side surface. Section **506** defines a passage through which molten metal may pass, and any shape or size passage suitable for efficiently conveying molten metal may be used.

Second section **505** is preferably 10" in length (although any suitable length may be utilized) and has a top surface, a bottom surface, a first side surface and second side surface. Section **505** defines a passage through which molten metal passes and any shape or size passage suitable for efficiently conveying molten metal may be used. Section **505** preferably has a height of about 4" and width of about 5½" for a pump utilizing a rotor with a diameter of 10". Section **506** has a height of about 4" and width of about 6½" for a pump utilizing a rotor having a diameter of 16", and preferably has a cross-sectional area between about 110% and 350% larger than the cross-sectional area of section **506**. However, all that is necessary for the proper functioning of the invention is that the cross-sectional area of section **505** be sufficiently larger than the area of section **506** to reduce the amount of pressure required for gas to be released into the molten metal stream as compared to the pressure required to release gas into a metal-transfer conduit that has substantially the same cross-sectional area throughout.

Alternatively, conduit path **504** could have multiple cross-sectional areas, as long as there is a transition from a first section with a first cross-sectional area to a second section with a second cross-sectional area, wherein the second section is downstream of the first section and the second cross-sectional area is greater than the first cross-sectional area. It is preferred that there be an abrupt transition from the first section having a first cross-sectional area to a second section having a second, larger cross-sectional area, however, the transition may be somewhat gradual, taking place over a length of up to 6" or more.

A gas-release opening **508** is formed in second section **505** through the bottom surface metal-transfer conduit **500**. Gas-release opening **508** is any size suitable for releasing gas from an opening in gas-transfer foot **300** into conduit path **504**. It is preferred that gas-release opening **508** be formed outside of the high-pressure flow of the molten metal stream (such as in section **506**), but it can be positioned anywhere suitable for releasing gas into conduit path **504**. For example, as shown in FIG. **5**B gas-release opening **508** may be formed in first section **506** near (preferably within 3") second section **505**. All that is necessary for the proper functioning of the invention is that there be (1) a first section of a metal-transfer conduit having a first cross-sectional area and a second section of the metal-transfer conduit downstream of the first section, wherein the second section has a second cross-sectional area larger than the first section, and (2) a gas-release opening in the bottom surface of the first section and/or the second section, whereby the respective sections are configured and the gas-release openings is positioned so that less pressure is required to release gas into the molten metal than would be required in known metal-transfer conduits that have substantially the same cross-sectional area throughout. Thus, in addition to a gas-release opening being formed in the first section or the second section, a gas-release opening could be formed in the first section and another gas-release opening could be formed in the second section, and gas could be released simultaneously into each section, or into one section or the other.

Metal-transfer conduit **500** also includes a gas-transfer foot notch **509** for attachment of a gas-transfer foot. The notch is shaped so as to accept the gas-transfer foot. Preferably, notch **509** is positioned in the bottom surface of metal-transfer conduit **500** so that the weight of the conduit secures the gas-transfer in position. Though not required, the foot may be cemented in place or otherwise be maintained in place by any suitable means As with the notch in the pump base, notch **509** may includes one angled side to accept a gas-transfer foot with an angled side. However, any shape notch is suitable as long as the gas-transfer foot is secure when inserted into the notch. In addition, notch **509** should be constructed so that the gas outlet port of the gas-transfer foot is in communication with the gas-release opening when the gas-transfer foot is inserted into the notch.

FIGS. **6**A-D show photographs of other views of metal-transfer conduits and gas-transfer assemblies according to various aspects of the invention.

Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

What is claimed is:

1. A gas-transfer foot for a molten metal pump having a pump base with a top surface, a bottom surface, and a notch in the bottom surface, the gas-transfer foot configured to be received in the notch and comprising:

(a) a top surface and a gas inlet port through which gas passes into the foot, the gas-inlet port in the top surface and configured to attach to a gas-transfer conduit; and

(b) a first end having a first outer cross-sectional area, and a second section that narrows from the first outer cross-sectional area to a second outer cross-sectional area, the first outer cross-sectional area being larger than the second outer cross-sectional area, and the gas-release port being formed at an end of the second section;

wherein when the gas-transfer foot is received in the notch the gas-release port can transfer gas into a flow of molten metal moving through the pump base.

2. The gas-transfer foot of claim **1**, wherein the notch is formed in the molten metal pump such that when the gas-transfer foot is inserted into the notch it is in communication with a gas-release opening in communication with the flow of molten metal.

3. The gas-transfer foot of claim **1** wherein the gas-transfer foot is comprised of graphite.

4. The gas-transfer foot of claim **1** wherein the opening is threaded.

5. The-gas-transfer foot of claim **1** wherein the opening has a surface area at least half as large as the surface area of the top surface.

6. The gas-transfer foot of claim **1** wherein the second section has a side surface and the gas outlet port is in the side surface.

7. The gas-transfer foot of claim **1** that further includes a gas-transfer conduit having a first end and a second end, wherein the second end is received in the gas-inlet port.

8. The gas-transfer foot of claim **1** wherein the gas-inlet port includes grooves for receiving an end of the gas-transfer conduit.

9. The gas-transfer foot of claim **7** wherein the inlet port includes grooves for receiving the second end of the gas-transfer conduit, and the second end of the gas-transfer tube is threaded; the second end of the gas-transfer tube being threadingly received in the gas-inlet port.

10. The gas-transfer foot of claim **1** wherein the gas-inlet port is in the first section.

11. The gas-transfer foot of claim **1** wherein the second outer cross-sectional area is 50% or less of the first outer cross-sectional area.

12. The gas-transfer foot of claim **1** wherein the second end has a top surface, a bottom surface, and a side surface, and the gas-release port is formed in the side surface.

13. The gas-transfer foot of claim **1** wherein the gas-inlet port has a diameter that is at least twice the diameter of the gas-release port.

14. The gas-transfer foot of claim **1** that includes a passageway between the gas-inlet port and the gas-release port.

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